CHEESEWEED (*Malva parviflora* L.) COMPETITION WITH CABBAGE AND LETTUCE ON MAUI, HAWAII

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ABSTRACT

In four field experiments transplanted cabbage was grown with cheeseweed sown at transplanting at densities from 0 to 70 weeds per 0.1 m^2. Cheeseweed emerged in 3 to 7 days and overgrew the cabbage in 42 to 49 days. At harvest cabbages were trimmed to two wrapper leaves and weighed. Final weed densities and weed fresh weights were recorded. Curvilinear and linear relationships between trimmed cabbage fresh weight and weed density were defined by regression equations. Regression equations were also calculated to define the relationship between cabbage fresh weight and weed fresh weight. In two additional plantings, subplots with cabbage only, cabbage and cheeseweed, and cheeseweed only were harvested weekly. Reductions in cabbage plant fresh weights occurred when cheeseweed attained and surpassed the height of the cabbage.

One experiment was conducted with transplanted lettuce and cheeseweed sown to densities from 1 to 15 weeds per 0.1 m^2. The relationship between trimmed lettuce head fresh weights in grams (y) and the number of weeds per 0.1 m^2 (x) was best expressed by the linear equation $y = 842 - 49.4x$. When y was regressed on weed fresh weight in grams per 0.1 m^2 (x), the equation was $y = 929 - 2.3x$. In addition to reduced head weights, losses due to rot increased with increasing weed densities, with a stand reduction as high as 80 percent at 5 weeds per 0.1 m^2.

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INTRODUCTION

Cheeseweed (*Malva parviflora* L.) has become a problem in cabbage and lettuce production in the Kula district of Maui, Hawaii due to its tolerance of herbicides currently labelled for use in these crops. Cheeseweed has been described as an annual or biennial European broadleaf (25,35,42). At 300 to 525 meters, the elevations at which cabbage and lettuce are grown on Maui, cheeseweed behaves as an annual. Although it can be found the year round, it is more prevalent in the cooler months. The plant will attain heights of a meter or slightly more. Roundish leaves, commonly 4 to 8 cm in diameter, borne on numerous long stems, form a dense canopy above the vegetables. In general, cheeseweed emerging shortly after transplanting begins to shade the crop in about 4 to 6 weeks. Current grower practice is to hand weed the fields at least once during the 6 to 7 week cycle for lettuce or the 8 to 10 week cycle for cabbage. This study was undertaken to determine the influence of season-long competition of cheeseweed with cabbage and lettuce. The results would be useful to establish guidelines for effective control of cheeseweed.

LITERATURE REVIEW

In reviewing a number of interspecific competition studies, Milthorpe (38) concluded that competition between roots for mineral nutrients commences before competition for light. Shading of the weaker competitor is a result of a lower growth rate, due to a less aggressive root system, an inherent disadvantage in competing for available nutrients. An initial high level of nutrients in the media does not eliminate nutrient status as a causal factor in competition. To diminish the effect of nutrient status, the soil solution must be continuously replenished to maintain fertility throughout the root zone.

Milthorpe (38) contended that under conditions of high soil fertility root expansion is stimulated most in the species with the greater growth potential, the more aggressive species. This effect was demonstrated by Kleinig and Noble (32) in their study on the effects of nitrogen and phosphorus fertilization in rice (*Oryza sativa* L.) under competition with barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.). Increasing the level of nitrogen applied from 137 to 275 kg/ha while withholding phosphorus intensified competition as was evident by the increase in the rice yield regression slopes: $\log y = -\underline{0.099}x + 3.503$ with 137 kg/ha N and $\log y = -\underline{0.137}x + 3.394$ with 275 kg/ha N, where y is pounds of fullrice grain per acre and x is the number of weeds per ft^2. Addition of phosphorus further intensified competition as demonstrated in the equations: $\log y = -\underline{0.217}x + 3.331$ with 137 kg/ha N and 54 kg/ha P, and $\log y = -\underline{0.374}x + 3.042$ with 275 kg/ha N and 54 kh/ha P. Barnyardgrass tillers earlier than rice, a competitive advantage (27), and tillering is stimulated by the addition of the superphosphate (32). Kleinig and Noble concluded that a relatively small population of weed seedlings can become a serious problem under high fertility conditions. Boerema (6) found that barnyardgrass absorbes 50 percent more nitrogen than rice, and when weeds are removed rice uptake of nitrogen increases threefold. Buchanan and Burns (9,10) found that cotton (Gossypium hirsutum L.) yield reductions at all weed densities of sicklepod (Cassia obtusifolia L.) and redroot pigweed (Amaranthus retroflexus L.) were greater on a fertile sandy clay loam with good moisture holding capacity than on a drier, less fertile sandy loam. Under the conditions favoring good vegetative growth the weeds gain an early advantage.

Many researchers have found that in well-fertilized crops in irrigated fields, light may be the only factor for which there is competition (4,17,20,21).

Creel et al. (16) found that changing the level of nitrogen, potassium, and phosphorus in the media produces comparable relative growth changes in cotton and sicklepod. They concluded that changing the level of fertility would not likely change the relative competitiveness of the two species.

It is generally recognized that competition for light is a function of the heights of the competing species and that small differences can have substantial ecological importance (21). The initial slight advantage of one plant over another becomes exaggerated over time (38).

Optimum utilization of solar radiation occurs when there is maximal absorption by the leaves. This absorption is a function of the leaf area per unit ground space, or the leaf area index. The optimal leaf area index varies with the species depending on its growth habit. Blackman and Black (4) postulated that under conditions where temperature, water, and nutrient supply do not restrict growth, maximal production of dry matter per unit area will be limited by the leaf area index and the amount of solar radiation.

In most plant communities there is not only interspecific competition for light but also competition among leaves of the same plant. As the light intensity increases, the rate of net photosynthesis increases for a plant, a tree, or a plant community as more leaf surface approaches light saturation (21). Light saturation of individual leaves of many crop species may occur at light intensities on the order of 6,456 to 21,520 lux (4). Plant species vary widely in their light requirements.

Reduced radiation falling on the weaker competitor can affect the rate of root expansion and nutrient uptake before the relative growth rate is affected (38). Shading does not reduce the relative growth rates of most plants until visible radiation falls to 100 to 150 cal. cm^{-2} day^{-1} (5). Eventually, the less successful species is shaded to the degree that the rate of leaf expansion is also reduced.

The competitive advantage of a dominating species often lies in its greater stature. Black (3) demonstrated that with three varieties of subterranean clover (Trifolium subterraneum L.), that with the longer petiole is always more successful in intervarietal competition. Tall, late maturing varieties of soybeans (*Glycine max* (L.) Merr.) usually are better competitors with weeds than short, early maturing cultivars (11,37,47).

Roberts et al. (44) determined that drilled lettuce (*Lactuca sativa* L.) in Warwick, England could tolerate competition from tall growing lambsquarter (*Chenopodium album* L.) for about 3 weeks after 50 percent crop emergence compared to 6 weeks when weeds were low growing species. Roberts et al. (43) conducted a similar series of experiments with drilled summer cabbage (*Brassica oleracea* L. var. *capitata*). Natural weed populations were allowed to compete for various periods of time before being removed and in other plots weeds were controlled for various periods and then allowed to compete. When weeds were removed 3 weeks after 50 percent crop emergence, there was no difference in yield from that of weed-free controls. When weeds at 90 per m^2 competed for the entire crop cycle yields were reduced to 5 percent of the controls. Control of weeds for 2 to 3 weeks after 50 percent crop emergence was as effective as season long weed control. Floresca and Nishimoto (24) found that 30 Emilia (*Emilia fosbergii* Nicholson) plants per 0.09 m^2 reduce direct seeded lettuce, mustard cabbage (*Brassica juncea* L.), and corn (*Zea mays* L.) and transplanted tomato (*Lycopersicon esculentum* Mill.) yields by about 90, 50, 0, and 20 percent, respectively. Corn, growing taller than Emilia retards weed growth, whereas, in lettuce Emilia begins shading the crop about 27 days after planting. Densities of 5, 11, 27, and 48 weeds per 0.09 m^2 are estimated to provide 35, 90, 98, and 96 percent shade, respectively, in the lettuce.

Roberts and Bond (42) found little relationship between the densities of naturally occurring weed populations and the marketable yield of drilled summer cabbage because species makeup of the weed complex varied in their herbicide trials, as did the time of emergence of weed seedlings relative to the crop. Reductions in the weight of marketable yields over 4 seasons were 9, 25, 46 and 75 percent. The lowest yields were obtained when lambsquarters and stinging nettle (*Urtica urens* L.) were the predominant species in a weed complex at about 300 weeds per m^2. When lower growing chickweed (*Stellaria media* (L.) Cyrillo) and knotweed (*Polygonum aviculare* L.) were predominant at an average density of 86 weeds per m^2, yields were reduced by 46 percent.

Lawson (28) conducted three experiments on spring germinating weeds in cabbage that was fall transplanted for spring harvest. Annual bluegrass (*Poa annua* L.) covered the ground in untreated plots throughout the winter, but chickweed grew very vigorously in spring and dominated the weed complex. Chickweed grew taller than the crop, shading some portion of the crop foliage. In 3 annual experiments in which weed dry weights were 3.5, 3.0, and 9.5 tons/ha and were comprised of approximately 84, 72, and 88 percent chickweed, cabbage trimmed head weights in the unweeded plots were 66, 69, and 34 percent, respectively, of yields in the weeded controls. In comparing the time of first crop shading and the earliest evidence of first crop injury, Lawson concluded that visual assessment of shading would be a practical method of determining the onset of competitive effects on the crop.

Hewson (28) studied the effects of lambsquarter in drilled summer cabbage and lettuce. Populations of the weed were thinned to densities of 0, 2.3, 4.6, 9.5, 19.2, and 38.4 per m^2 and allowed to compete during the entire crop cycle. The number of marketable lettuce plants was reduced by 58 percent, and yield was reduced by 55 percent at 2.3 weeds per m^2. At densities of 4.6 and 37 yields were reduced by 89 and 100 percent, respectively. A curvilinear relationship was found with a log-log transformation of the data, with the regression equation $y = 65.6\ x^{-0.75}$ expressing lettuce yield (y) in tons per ha and weed density (x) as weeds per m^2. Lettuce yield (y) was also regressed on lambsquarter fresh weights at harvest (x) in tons per ha, and a linear equation best fit the data: $y = 39.9 - (0.94x)$. Linear regression equations were computed for cabbage yields (y), in tons per ha, and lambsquarter fresh weight at harvest (x), in tons per ha,: $y = 65.62 - (1.5x)$ and also with weed density (x), in plants per m^2,: $y = 61.83 - (1.56x)$. Examples of other regression equations in weed-crop competition literature are given in Table 1. Some examples of crop yield reductions under weed competition are given in Table 2.

The minimum time period that weeds must be controlled to avoid significant yield loss denotes the "critical weed-free requirement" (7,40). Weeds germinate and grow in the crop throughout the growing season, but the most serious competitors are those that emerge when the crop is young. In time, crops that develop a ground shading canopy will have a competitive edge that will suppress late emerging weeds (9, 13,17). Usually, the early emerging weeds will compete vigorously with the crop resulting in yield loss if they are not suppressed by mechanical, chemical, or other control measures (13,56). Dawson (20) speaks of this as two-stage weed control. In stage 1 the grower control the weeds, whereas in stage 2 the vigorous, full stand, crop growth suppresses weeds in late season. Weed control is stage 2 is mainly through competition for light. Often the minimum period of weed-free growth is about one third the life cycle of the crop (31). Noncompetitive crops such as onions (*Allium cepa* L.), garlic (*Allium sativum* L.), and carrots (*Daucus carota* L.) need a longer period of weed control (54,55).

Most experiments looking for the weed-free requirement are conducted by removing weeds in the plots for different periods after planting and thereafter allowing late emerging weeds to grow or by sowing weed seed in the plot if necessary. This type of study has been done with corn (1,34), field beans (*Phaseolus vulgaris* L.) (17,20), cotton (10), cabbage, tomatoes, carrots, okra (*Hibiscus esculentus* L.), snap beans (*Phaseolus vulgaris* L.), cucumbers (*Cucumis sativus* L.) and garlic (55), peanuts (*Arachis hypogaea* L.) (29), sorghum (*Sorghum bicolor* (L.) Moench) (13,14,40), sugarbeets (*Beta vulgaris* L.) (19,20,53), and soybeans (*Glycine max* Merr.) (2,23,34).

Some researchers have subdivided plots and removed the crop from one half at the end of the weed-free period to study the effects of the crop on late emerging weeds. Under competition from field beans, late emerging barnyardgrass growth was reduced nearly 80 percent after 2 weeks of early weed control, whereas, when beans were removed after 2 weeks of weed control, weed growth was reduced only about 10 percent (17,18).

Most crops can tolerate weed growth during some portion of their early development without adverse effect on the final yield (9). The specific length of time depends on the crop, its growth habit, the weed species, their growth habits, and the time of weed emergence (5,9,19,30,41,48,49,57). Where competition for water is a factor, crops are less tolerant to weed pressures. Fast growing crops like corn, soybeans, and field beans can have an early competitive advantage, unlike initially slow growing crops such as okra (55). Experiments to determine the period of early weed competition that crops can tolerate without significant yield depression are conducted by allowing weeds to compete for different lengths of time before removing them. Removal must be done without disturbing crop roots. Usually, this is accomplished by using sharp knives, hoes, or clippers to cut the weeds at the soil surface.

Other studies have been conducted with crops competing with different densities of weeds for the entire crop cycle, including corn (34), soybeans (2,26,34,56), corn, lettuce, mustard cabbage and tomato (24), and cotton (9).

Whereas some researches utilize a natural population of weeds, others establish specific densities by sowing seeds and thinning the seedlings. Plots often consist of four rows of the crop, 4.5 to 12 m long, the two center rows being harvested while the outside rows serve as borders (7,8,15,18,34).

The most common variable used to determine the effects on crop yield is the dry weight of the marketable product whether it be field beans (17), cotton (8), soybeans (50,56), or lettuce (24). Some researchers have measured the fresh weight of the marketable product, especially vegetables (24,44,55). Usually, weed stand counts and dry weights are taken. Other variables looked at include cotton seed weight, cotton lint fiber properties, and percent lint (10), percent marketable yield of cabbage (43,44), plant height, soybean pod set and development period, soybean seed grade, percent oil, and protein content (2).

Several studies have shown that weed competition in soybeans has its greatest effect in reducing the number of pods per plant (12,22,33), but may also reduce the number of seeds per pod (12) or reduce seed size (22). Yield reduction in cotton is mainly a result of fewer bolls matured by the plants rather than reduced boll weight (9). Reduction in cabbage trimmed head weight, reduced total crop weight, and lower weight of marketable plants was reported by Lawson (36). Roberts and Bond (43) found that weed competition reduces cabbage plant size and the number of plants which form firm marketable heads and crop maturity is delayed.

Analysis of variance is commonly employed to determine if there are differences among treatment means. If treatment means are found to be different, then Duncan's Multiple Range test is used to group treatment means that are not significantly different (8,9,10,13,23,45,52). Regression analysis is used to estimate the effects on crop yields of different weed densities or weed weights (24,32,52).

Table 1. Some regression equations reported in competition studies

Relationship	Equation	r	Ref
lettuce dry weight (y) g	$y = 14.9 - 2.3 (x^{0.5})$	-0.86	24
Emilia stand count (x) (0.09 m^{-2})			
tomato fruit weight (y) g	$y = 12562 - 22 (x)$	-0.81	24
Emilia stand count (x) (0.09 m^{-2})			
tomato fruit weight (y) g	$y = 12661 - 220 (x^{0.5})$	-0.71	24
Emilia dry weight (x) (0.09 m^{-2})			
soybeans kg/ha (y) dry	$y = 2449 - 110.6 x$	0.57	52
sicklepod plants per m^2 (x)			
on a Chesterfield sandy loam			
on a Malbis sandy loam	$y = 2523 - 102.1 x$	0.88	52
rice kg/ha (y) no N	$\log y = 3.447 - 0.096 x$	-0.82	32
barnyardgrass plants per 0.1 m^2 (x)			
with 283 kg/ha N	$\log y = 3.804 - 0.137 x$	-0.81	32

Table 2. Results reported from some competition studies.

Crop	Weeds	Density	% Yield reduction	Soil	Ref
cabbage	annual broadleafs	300 m^{-2}	9		44
		97 m^{-2}	75		
	purple nutsedge*	160 m^{-2}	35		55
	annual broadleafs	50-540 m^{-2}	50-95		44
cotton	cocklebur	8/7.31 m*	20-40	sandy loam soil	10
		48/7.31 m	80		
	redroot pigweed	48/7.31 m	50		
	redroot pigweed	8/7.31 m	20-40	sandy clay loam	
		48/7.31 m	90		
	annual broadleafs	natural	90		8
	sicklepod	8/7.31 m	10-23	sandy loam	9
		48/7.31 m	45-65		
	tall morningglory	8/7.31 m	10-40		
	sicklepod	8/7.31 m	40	sandy clay loam	
		48/7.31 m	80		
	tall morningglory	8/7.31 m	50-75		
		48/7.31 m	85		
lettuce	annual broadleafs	65-130 m^{-2}	90-100		45
field beans	barnyardgrass	2.8-4/30 cm	50		17

MATERIALS AND METHODS

Transplants

Cabbage cultivar 'C-G Cross' and lettuce cultivar 'Mesa 659' transplants were grown at the Kula Branch Research Station at Waiakoa. Two hundred count, 2.5 by 2.5 cm Speedling trays were used with a Promix A potting mix, consisting of equal parts vermiculite and peat with 15 kg/m^3 osmocote (14-14-14) added. Seedlings were watered daily. Diazinon and maneb sprays were applied biweekly.

Seedlings at transplanting were 32, 38, 27, 35 days old for experiments 1, 2, 3 and 4, respectively. The transplanting dates were June 29, 1982; December 27, 1982; May 5, 1983; and July 7, 1983. Field spacings for transplants were 45 cm by 55 cm for cabbage and 35 cm by 40 cm for lettuce.

Field Plots

Field plantings were made at the Pulehu Substation Facility (elev. 640 m). Plot P1, consisting of 259.2 m^2, was used for all cabbage full term competition experiments. Land was cleared in a field adjacent to the research facility in early 1983. Plot P6 in this new field, consisting of 369 m^2, was used for the cabbage growth analysis experiments. A lettuce full term competition experiment was conducted in P1.

Irrigation and Pest Control

Plots were sprinkler irrigated for 1 hour on Mondays, Wednesdays, and Fridays, delivering approximatesly 2.5 cm of water per application. Weekly pesticide applications were made to control insect and disease pests (Tables 3,4,5,6). Sprays were applied by a tractor mounted Meyers sprayer with a hand held wand. Good coverage of the crop was maintained even at high weed densities.

Plant Propagation and Fertilizer Application

Primary plot tillage was accomplished by several passes with a rotovator. Fertilizer was then boradcast and tilled in to a depth of 20 cm with an additional pass with a rotovator. A side-dress application of granular fertilizer was applied in a band along the row about 7 cm from the plants at 4 to 6 weeks after transplanting. Fertilizer application is detailed in Tables 7 and 8.

Cheeseweed Seed

Cheeseweed seed was collected from mature plants in the Pulehu area 1 to 3 months prior to sowing. Seeds for experiments 1 and 2 were scarified by treating the seed in 93 percent technical grade sulfuric acid for 20 minutes, followed by a thorough rinsing with tap water, and 12 hour soaking in tap water. Seeds for experiments 3 and 4 were scarified for 2 minutes in a Forsberg electric seed scarifier. These seeds also were soaked in tap water for 12 hours. After the soaking period, the seeds were placed on newspaper to dry so seeds did not stick together and could be hand broadcast in the plots.

Seed lots were weighted out for each treatment subplot assuming a 2.5, 20, 10, and 10 percent germination rate for experiments 1, 2, 3 and 4, respectively.

The seed was broadcast and lightly raked into the soil on the day of cabbage tranplanting, except for experiment 3 when seed was sown 2 days prior to transplanting.

Cheeseweed plants were thinned to desired densities twice during the first few weeks of the trial as listed below:

Experiment	Days after transplanting	
	Thinning	
	1st	2nd
1	14	28
2	17	42
3	19	27
4	-	28

Experimental Design

A randomized complete block design was employed in all experiments with treatments in each experiment replicated 4 times. Full term competition trials were conducted with either 6 or 7 weed density treatment levels. Treatment subplots were always separated by a single guard row of the crop under study.

Cheeseweed Density Treatments in Cabbage

Experiment	Weeds per 0.1 m^2	Cabbages per subplot
1	0, 1, 2, 4, 8, 16	20
2	0, 0.25, 0.50, 1, 2, 4, 8	24
3	0, 0.25, 0.50, 1, 2, 4, 8	20
4	0, 0.25, 0.50, 1, 2, 4, 8	20

Cheeseweed Density Treatments in Lettuce

Weeds per 0.1 m^2	Lettuce plants per subplot
0, 1, 2, 4, 8, 16	20

Growth analysis experiments for cabbage and cheeseweed were conducted simultaneously with full term competition trials 3 and 4. The three plots were weed-free cabbage, cabbage-free cheeseweed, and cabbage with cheeseweed. Plots were divided into 9 subplots for the 9 weeks that the experiment was expected to run. Each week one subplot in each of the three main plots was harvested. Subplots containing cabbage consisted of two rows of three cabbage plants, while cabbage-free subplots contained the same area as the cabbage subplots and, like the cabbage plots, were outlined by a guard row of cabbage.

Harvesting and Collection of Data

Full term competition experiments

Plots were harvested when wrapper leaves on cabbage heads in the control subplots showed signs of cracking or when lettuce heads were mature and marketable. Full term competition trials with cabbage were harvested August 26, 1982; March 3, 1983; July 6, 1983; and September 7, 1983. The corresponding days to maturity were 58, 78, 62, and 62 days, respectively. The full term competition with lettuce was harvested on August 19, 1982, 51 days after transplanting. All plants were cut at ground level, and only the above ground portion was measured. Data taken for these experiments included the following variables recorded for each subplot:

Harvest measurements	Experiment			
	1	2	3	4
whole crop plant fresh wt.		*	*	*
crop head wt.	*	*	*	*
total no. weeds in subplot	*	*	*	*
fresh wt. of weeds in subplot	*	*	*	*
no. of seed discs per 10 weeds		*		*
cheeseweed ht. for 10 plants		*	*	*
cheeseweed wt. for 10 plants		*		
Weekly measurements				
cabbage plant ht.			*	*
cheeseweed ht.			*	*
presence of weed flowers			*	*
presence of weed seed capsules			*	*

Cabbages and lettuce were weighed as subsamples of 10 or 12, with two subsamples per subplot.

Growth Analysis Experiments

For experiments 3 and 4 in plot P6, subplots were harvested weekly. The experiments were terminated once the cabbage in plot P1 was harvested. The folowing data observations were recorded:

	Cabbage only	Cheeseweed only	Cabbage and cheeseweed
plant height	*	*	*
(6 cabbage and 10 cheeseweed)			
plant fresh weight	*	*	*
(6 cabbage and all cheeseweed)			
head diameter	*		*
number of cheeseweed		*	*
presence of weed flowers		*	*
presence of weed seed		*	*

Statistical Treatment of Data

Data, when appropriate, were tested by the Kolmogorov-Smirnov test for normality, and were found to be normaly distributed. Data from full term competition experiments in plot P1 met the assumptions of Model 1 linear regression. A least squares linear regression line was calculated using the Statistical Analysis Systems program on the UH IBM 3081 mainframe computer.

Data from experiments in plot P6 were tested by analysis of variance.

Degrees of freedom for regression analysis for cabbage plots.

	Experiment			
Source of variation	1	2	3	4
model	1	1	1	1
error	34	54	52	54

Degrees of freedom for treatment comparison in plot P6.

	Cabbage data		Weed data	
	Experiment			
Source of variation	3	4	3	4
treatment	1	1	1	1
replications	3	3	3	3
error	397	397	695	695

Degrees of freedom for analysis of seed production.

	Experiment	
Source of variation	2	4
weight classes	8	10
error	17	16

RESULTS AND DISCUSSION

Cabbage

Data analysis was performed regressing trimmed cabbage head fresh weight (y) on weed density (x^d) and on weed weight per 0.1 m^2 (x^w). Linear, quadratic, logarithmic, and exponential models were fitted to the data. In every case a highly significant negative regression was present. Coefficients of determination for exponential models were generally slightly higher than for others (Figures 1,2,3,4).

Log transformed y values of zero were detected as outliers with high leverage and greatly affected the slope of regression lines. These observations, 2 in experiment 3 and 1 in experiment 4, were excluded in exponential regression models. Regression analysis for the first experiment was conducted once including all data points and again excluding observations of x^d greater than 7 for comparison with other experiments which did not attain x^d values above 7. This had the effect of increasing the slope of the line in both the linear and exponential models, but the change was relatively small and little affected the magnitude of the difference between the slope of the line for experiment 1 and the slopes of those for other experiments.

All data points for experiment 1 were included in regressions with x^w (Figures 3, 4, 7, 8, 9). Two experiments did not attain values of x^w above 220, whereas experiments 3 and 4 had 12 and 5 observations above 220, respectively. In Figure 9 regression equations are presented in which values of x^w above 220 were excluded.

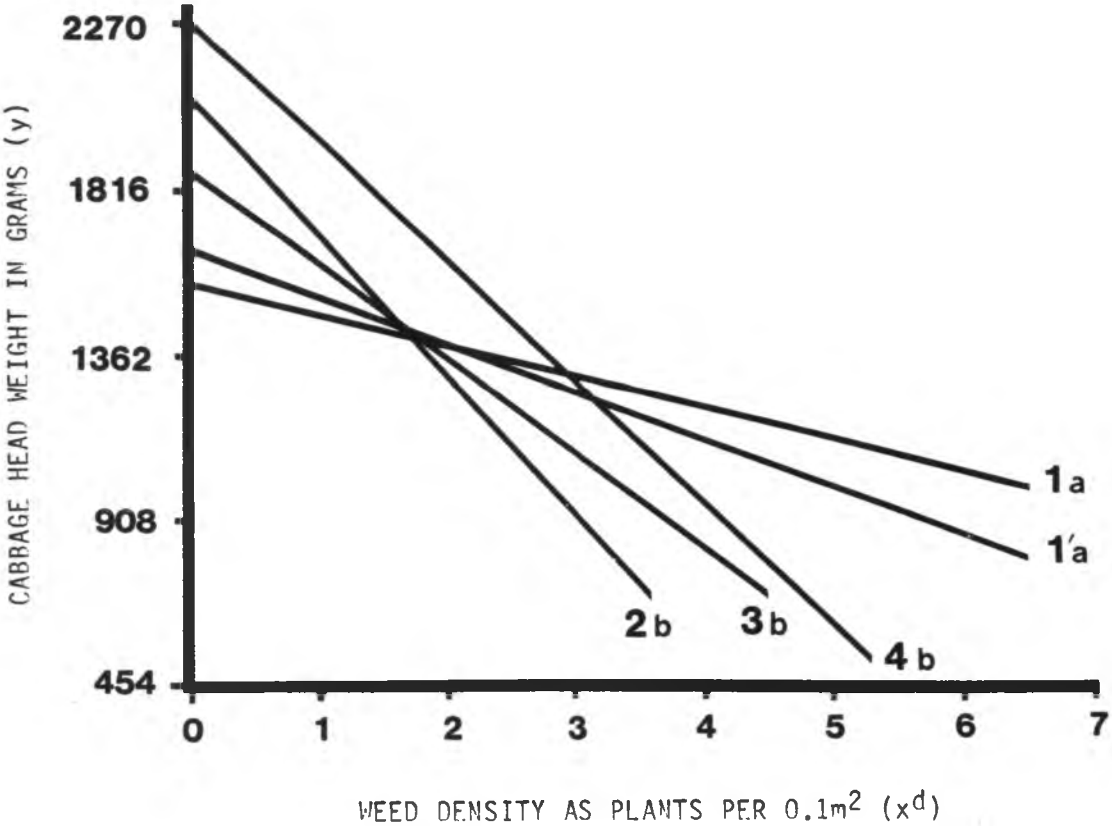

Figure 1. Regression lines expressing a linear relationship between trimmed cabbage head weight and cheeseweed density for 4 experiments. Equation 1' was calculated from experiment 1 data, but excluding data for x^d greater than 7, for comparison with experiments 2, 3, and 4, in which x^d did not exceed 7.

experiment number	regression equation	r^2	data used for calculation
1	$y = 1552 - 85x$	0.75	all values x^d
1'	$y = 1641 - 129x$	0.61	x^d less than 7
2	$y = 2070 - 382x$	0.57	all values x^d
3	$y = 1864 - 259x$	0.84	all values x^d
4	$y = 2274 - 330x$	0.55	all values x^d

Regression lines followed by the same letter are not significantly different by the Tukey-Kramer method for unplanned comparisons of regression coefficients (P=0.01).

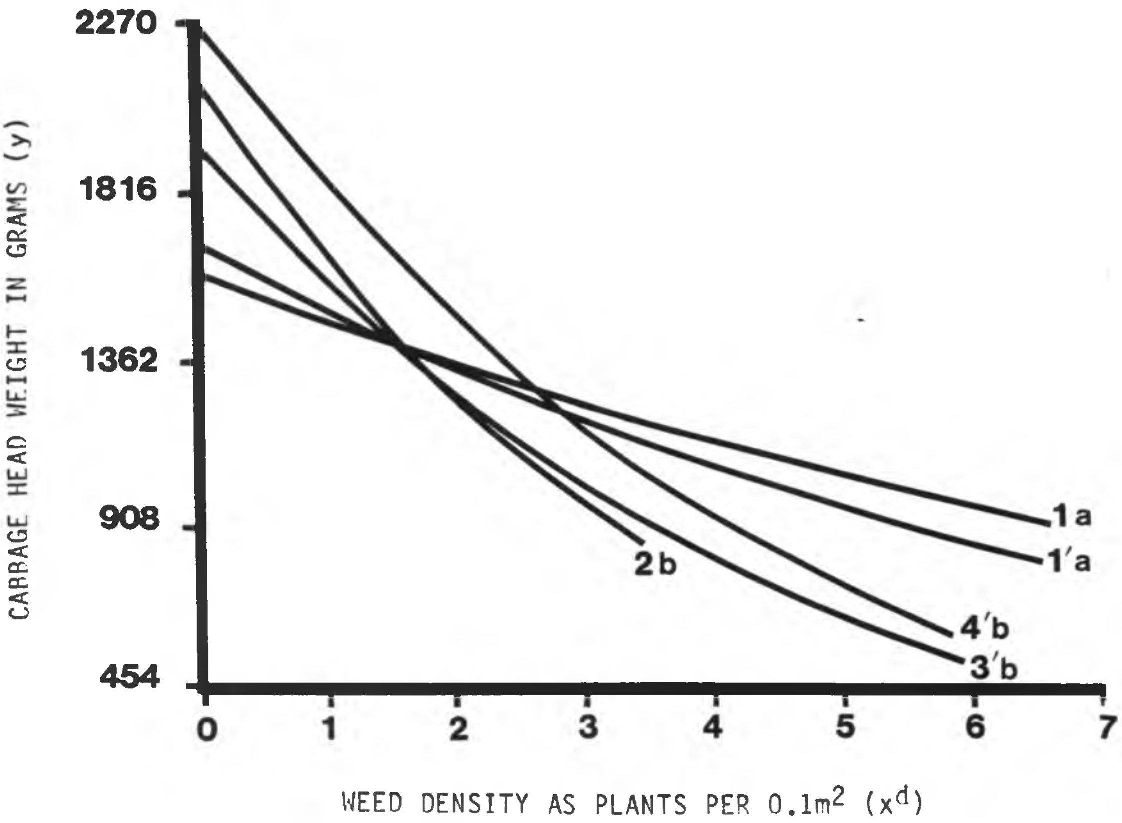

Figure 2. Exponential regression lines expressing a curvilinear relationship between trimmed cabbage head weight and cheeseweed density for 4 experiments. Equation 1' was claculated from experiment 1 data at x^d less than 7. Equation 3' and 4' were calculated ommitting 2 and 1 observations, respectively, where y was equal to 0, and which points became outliers when transformed into logarithms.

experiment number	regression equation	r^2	data used for calculation
1	$y = 1585\ (0.921)^x$	0.83	all values x^d
1'	$y = 1669\ (0.894)^x$	0.68	x^d less than 7
2	$y = 2118\ (0.769)^x$	0.55	all values x^d
3'	$y = 1946\ (0.803)^x$	0.87	$y = 0$
4'	$y = 2292\ (0.798)^x$	0.55	$y = 0$

Regression lines followed by the same letter are not significantly different by the Tukey-Kramer method for unplanned comparisons of regression coefficients (P=0.01).

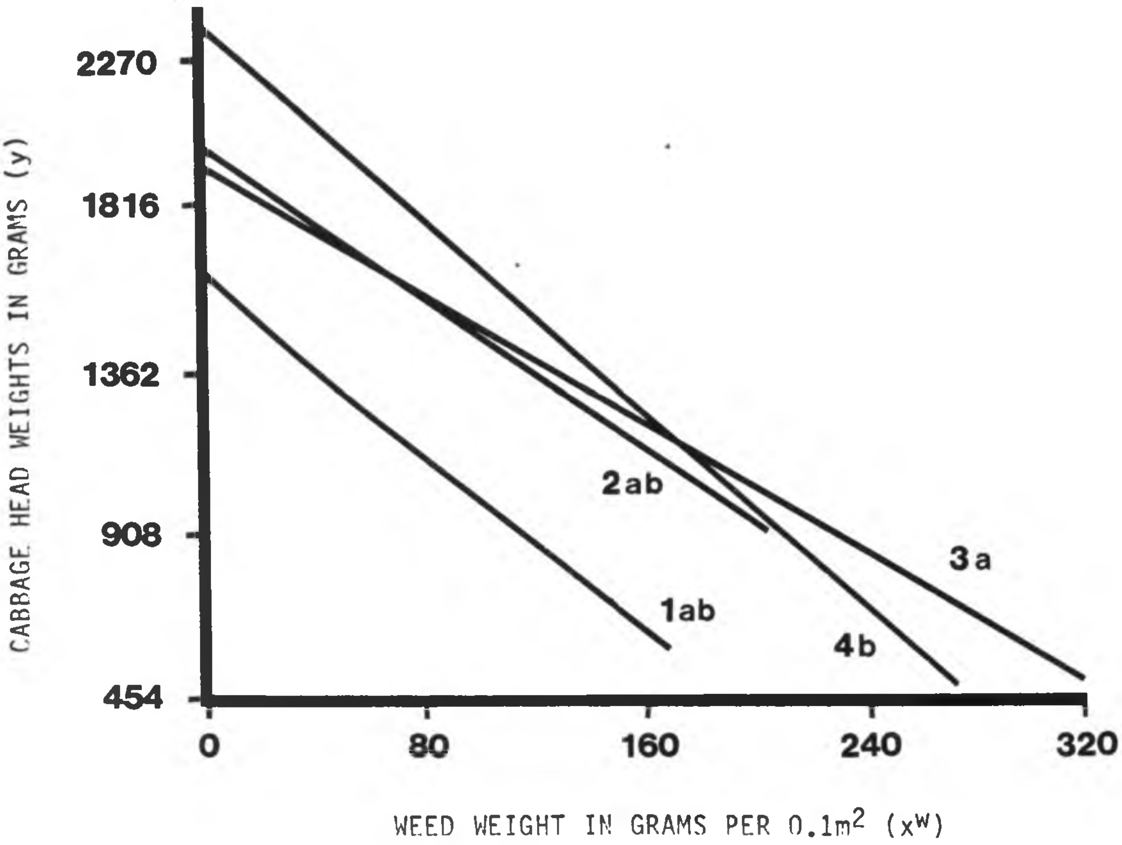

Figure 3. Regression lines expressing a linear relationship between trimmed cabbage head weight and cheeseweed fresh weight per unit area.

experiment number	regression equation	r^2	data used for calculation
1	$y = 1647 - 6.3x$	0.70	all values x^W
2	$y = 1987 - 5.2x$	0.48	all values x^W
3	$y = 1934 -04.5x$	0.85	all values x^W
4	$y = 2337 - 6.8x$	0.68	all values x^W

Regression lines followed by the same letter are not significantly different by the Tukey-Kramer method for unplanned comparisons of regression coefficients (P=0.01).

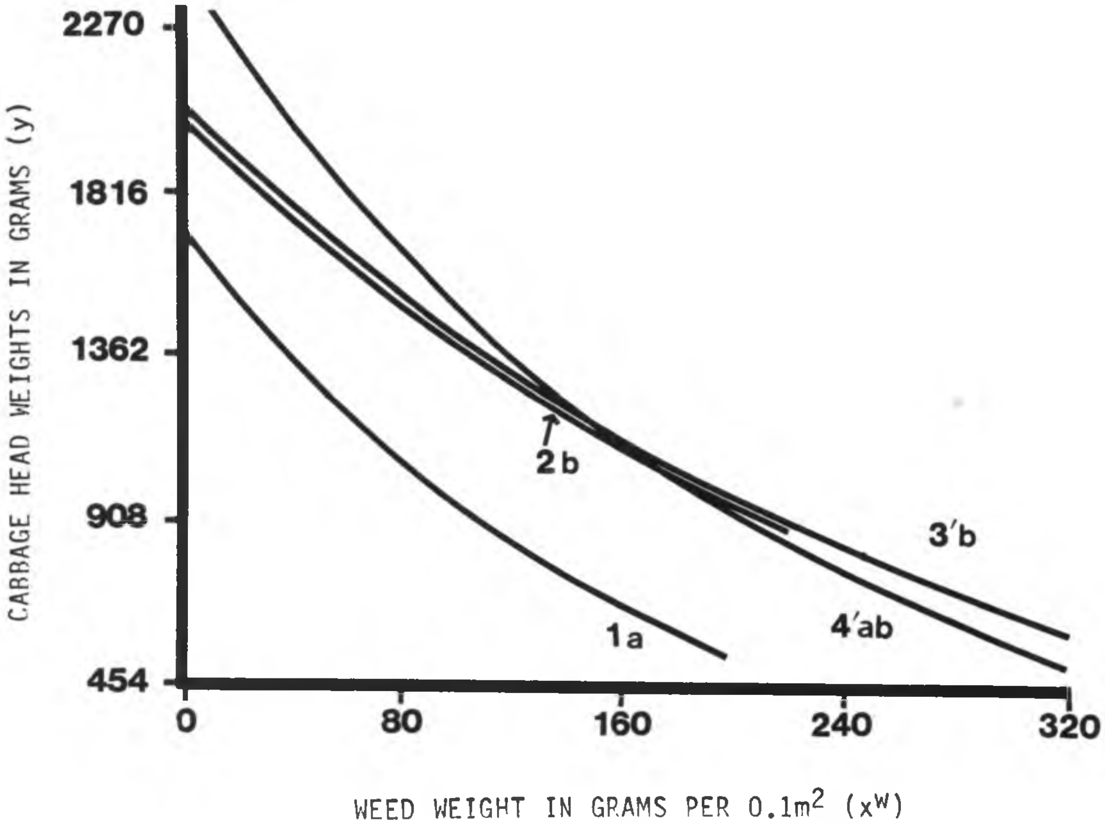

Figure 4. Exponential regression lines expressing a curvilinear relationship between trimmed cabbage head weight and cheeseweed fresh weight per unit area. Equation 3' and 4' were claculated omitting 2 and 1 observations, respectively, where y was equal to 0, and which points became outliers when transformed into logarithms.

experiment number	regression equation	r^2	data used for calculation
1	$y = 1718\ (0.99401)^x$	0.74	all values x^W
2	$y = 2018\ (0.99626)^x$	0.50	all values x^W
3'	$y = 2055\ (0.99622)^x$	0.83	$y = 0$
4'	$y = 2419\ (0.99519)^x$	0.74	$y = 0$

Regression lines followed by the same letter are not significantly different by the Tukey-Kramer method for unplanned comparisons of regression coefficients (P=0.01).

It is difficult to choose the most appropriate regression model for expression of these data. No pattern was discernible among the plots of standardized residuals for any regression model. However, with few intermediate to high values of x^d and x^w, patterns, if present, would be difficult to detect. Linear equations fit the data well, and a linear equation would seem appropriate in that the relationship appears to be an equi-dimensional trade off between the weight of cabbage and the weight of weeds (x^w) or the number of weeds (x^d). However, there are arguments in favor of the exponential model. First, the relationship between y and x may not have been equi-dimensional. Over time the weeds were growing taller as well as increasing in biomass. Once the weeds were taller than the cabbage an added dimension, that of the effects of shading, entered the relationship.

Considering the effects of shading, the detrimental effect on cabbage weight (y) may have been greater than a linear inverse relationship to the increase in weed weight (x^w) or weed density (w^d). In this case, cabbage head weight data points would curve downwards from the y axis and approach the x axis asymptotically. Log transformed y values would be more linear when plotted on semilog graph paper, as was true in these experiments. Regressing x on these transformed values yielded higher coefficients of determination for the most part, indicating that an exponential equation had a slightly better fit to the data.

Linear equations also have an x axis intercept, indicating that no growth is occurring beyond a certain value of x. In one subplot in each of the third and fourth experiments heads were not formed at high

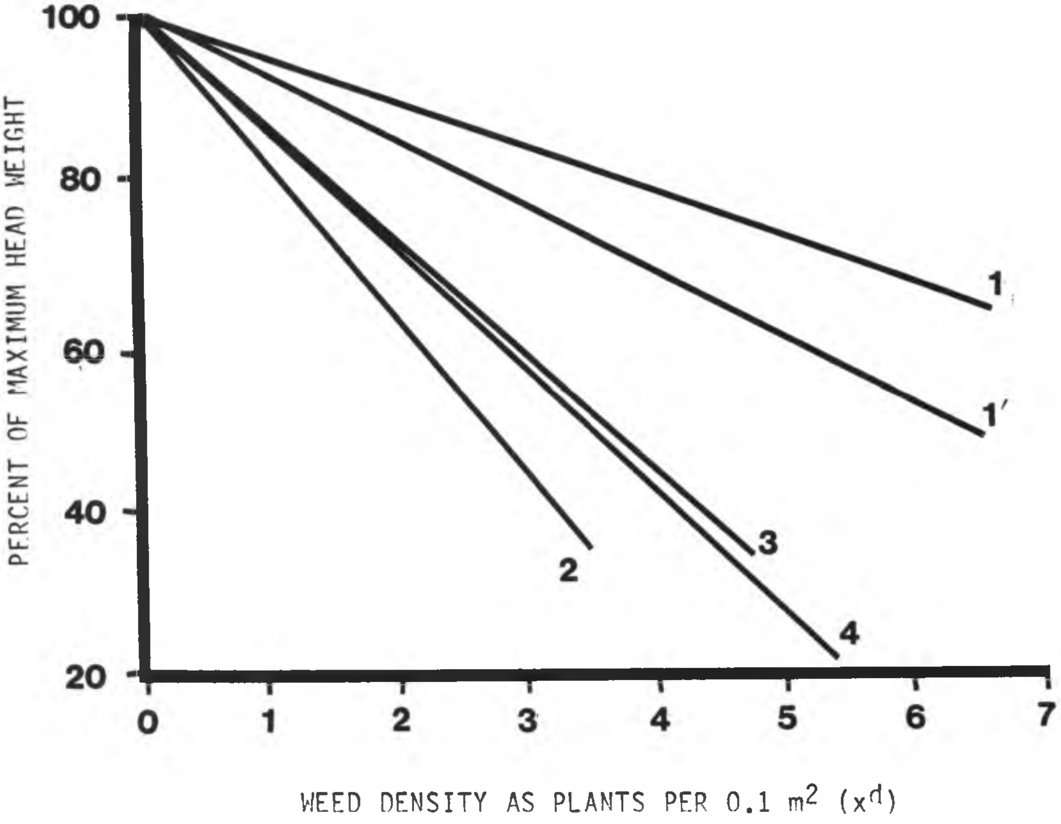

Figure 5. Percent of maximum head weight obtained at various cheeseweed densities in 4 experiments, as calculated from linear regression equations presented in Figure 1.

experiment number	equation of the line
1	$y = ((1552 - 85x)/1552)100$
1'	$y = ((1641 - 129x)/1641)100$
2	$y = ((2070 - 382x)/2070)100$
3	$y = ((1864 - 259x)/1864)100$
4	$y = ((2274 - 330x)/2274)100$

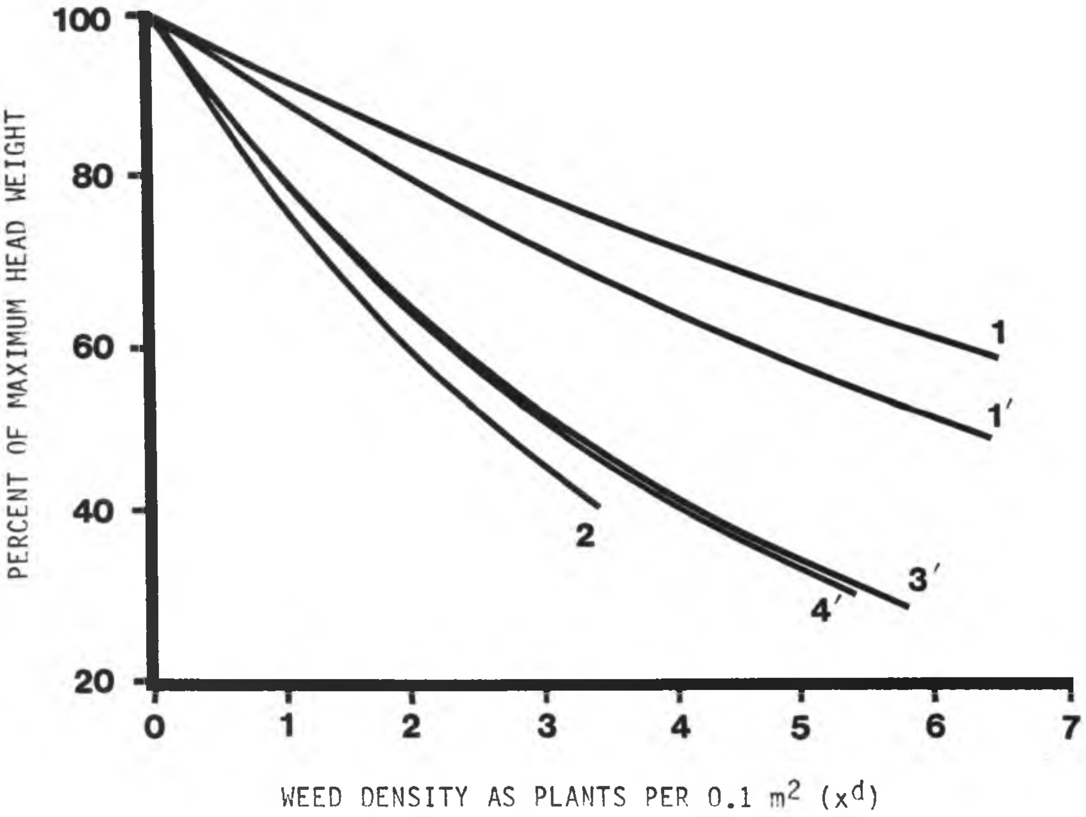

Figure 6. Percent of maximum head weight obtained at various cheeseweed densities in 4 experiments, as calculated from exponential regression equations presented in Figure 2.

experiment number	equation of the line
1	$y = ((1585\ (0.921)^x/1585)100$
1'	$y = ((1669\ (0.894)^x/1669)100$
2	$y = ((2118\ (0.769)^x/2118)100$
3'	$y = ((1946\ (0.803)^x/1946)100$
4'	$y = ((2292\ (0.798)^x/2292)100$

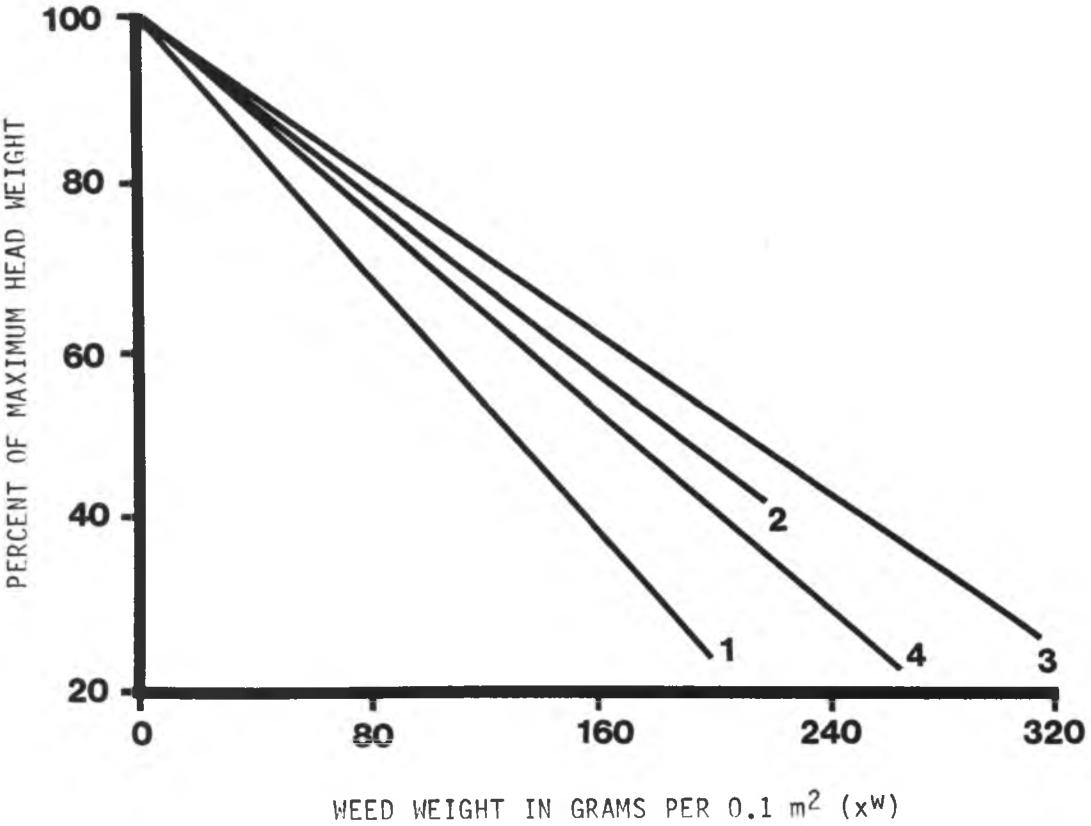

Figure 7. Percent of maximum head weight obtained at various cheeseweed weights per unit area in 4 experiments, as calculated from linear regression equations presented in Figure 3.

experiment number	equation of the line
1	$y = ((1647 - 6.3x)/1647)100$
2	$y = ((1987 - 5.2x)/1987)100$
3	$y = ((1934 - 4.5x)/1934)100$
4	$y = ((2237 - 6.8x)/2337)100$

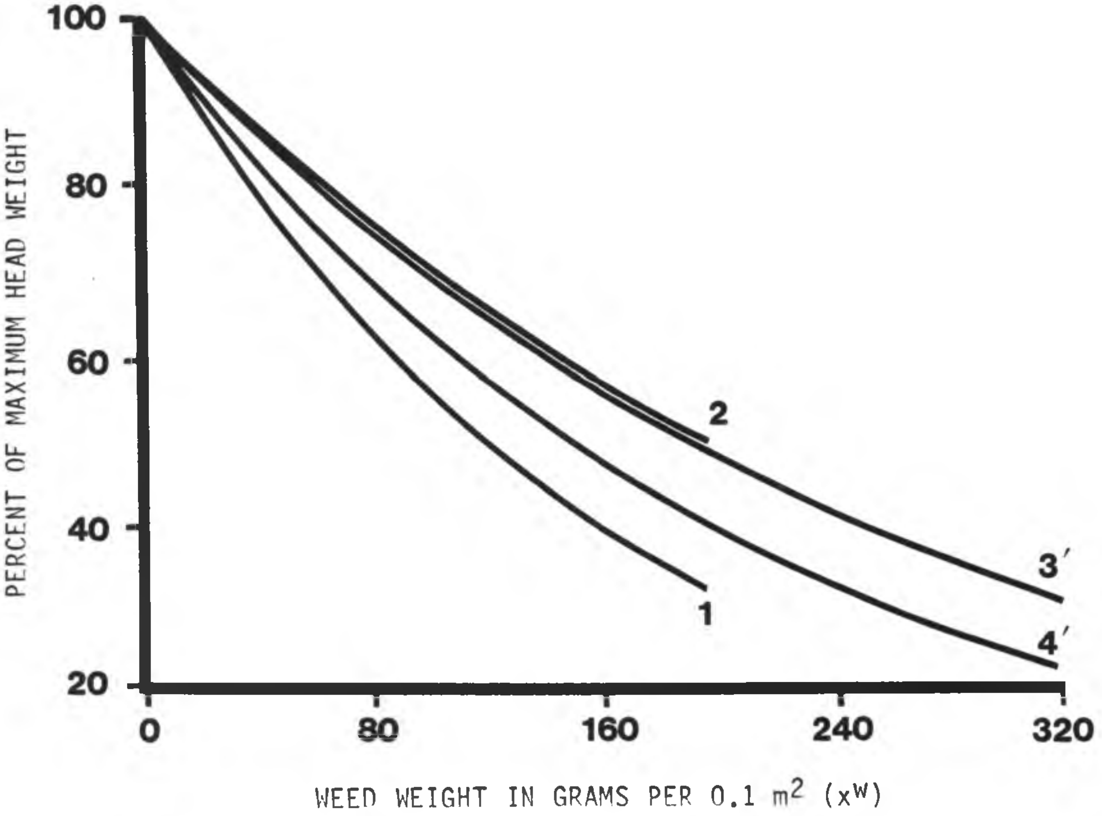

Figure 8. Percent of maximum cabbage head weight obtained at various cheeseweed densities in 4 experiments, as calculated from exponential regression equations presented in Figure 4.

experiment number	equation of the line
1	$y = ((1718\ (0.99401)^{x})/1718)100$
2	$y = ((2018\ (0.99626)^{x})/2018)100$
3'	$y = ((2055\ (0.99622)^{x})/2055)100$
4'	$y = ((2419\ (0.99519)^{x})/2419)100$

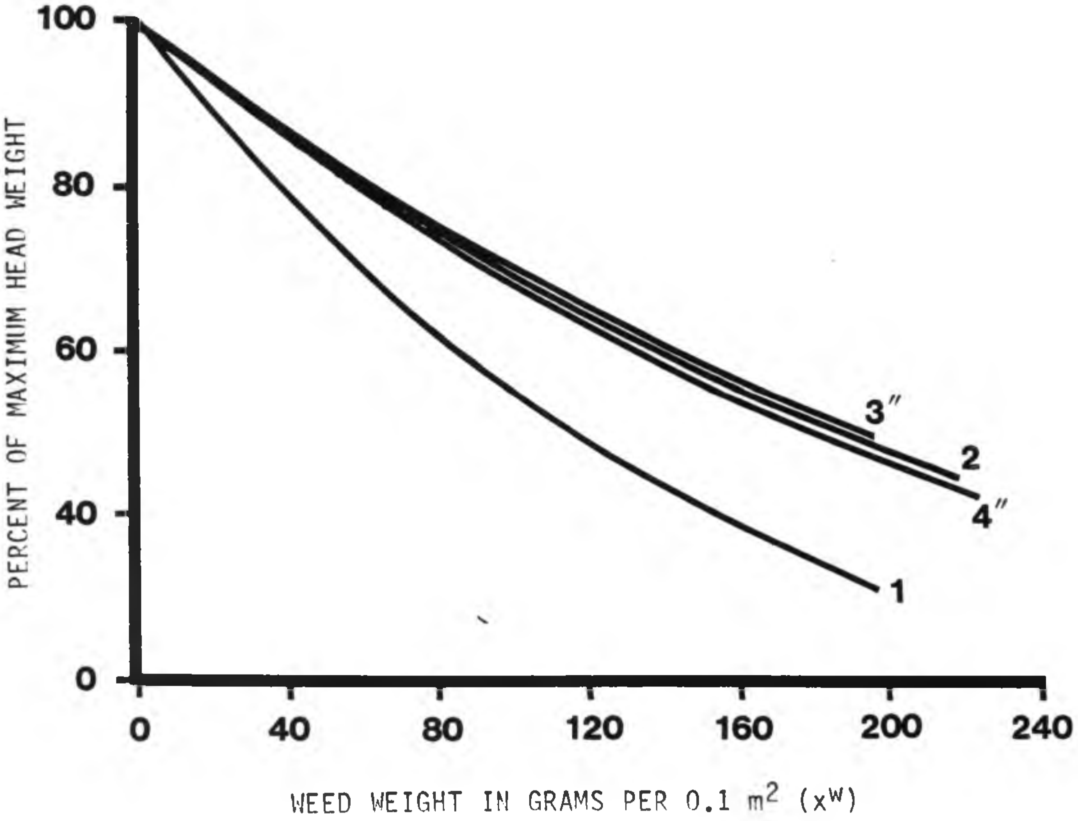

Figure 9. Percent of maximum cabbage head weight obtained at various weights of cheeseweed per unit area in 4 experiments, as calculated from the regression equations presented below. Y = trimmed cabbage head weight in grams.

experiment number	regression equation	r^2	data used for calculation
1	$y = 1718\ (0.99401)^x$	0.74	all values x^W
2	$y = 2018\ (0.99626)^x$	0.50	all values x^W
3''	$y = 2043\ (0.99631)^x$	0.70	x^W less than 230
4''	$y = 2326\ (0.99614)^x$	0.50	x^W less than 230

weed densities. These plants, under high weed pressure, did not form a compact head but some growth did occur. What could have been measured as the "head" was a small number of loosely cupped leaves, much like those in the late cupping stage. Had these leaves at the meristem been included in the data, head weights could have been considered to drop off asymptotically.

Cabbage yields differed among experiments (seasons) and the slopes of the regression lines appear to be of the same magnitude (Figures 1,2,3,4). Regression values are also plotted as a percentage of the predicted maximum cabbage head weight, the y intercept (Figures 5,6,7,8,9). In these plots regression lines for experiments 2, 3, and 4 are quite close. Tests for equality of slopes for the 4 experiments were conducted on data presented in Figures 1, 2, 3, and 4, but not for values as percentages of the intercept. Results indicated that at least 1 of the slopes was significantly different from the others in each model.

A procedure for unplanned comparisons among the 4 regression coefficients was carried out to determine which slopes were different. Results of the Tukey-Kramer method indicated that in most models the slopes for experiments 2, 3, and 4 were not significantly different, but the slope for experiment 1 was different from all others (P=0.01) (Figures 1,2,3,4).

In regressions with x^w, experiment 1 had a steep slope relative to other experiments, but the opposite is true in regressions with x^d, where experiment 1 had the least steep slope. The explanation of this paradox may be found in examining the relationship between x^w and x^d. Figure 10 is a plot of linear regression lines for the four experiments, regressing x^d on x^w. While there seems to be relatively little difference in regard to these parameters for the last three experiments, the first experiment stands apart. There was substantially less biomass at any weed density (x^d) in experiment 1 as compared to the others. Conversely, at any weed weight (x^w) there were over three times as many weeds at harvest in the first experiment as there were in the others.

There was a difference in the establishment of the weed stands that may explain differences in stand composition at harvest. The first experiment may have had a large number of weeds emerging after thinning relative to the other experiments due to a high rate of seeding in that first trial.

From preliminary laboratory experiments, cheeseweed seed germination was predicted to be near 5 percent within 2 weeks. Seed was sown at twice the rate of expected germination to insure a full stand. Actual germination was several times higher than predicted and there was a dense flush of weeds within a few days of sowing. These weeds were thinned in the second and fourth week, but there remained a large reservoir of seed in the plot.

Weed counts were not recorded at thinning and it is not known how many of the weeds counted at harvest emerged subsequent to thinning. There is a the probability that some late emerging weeds were counted at harvest in all subplots, across all experiments, but with perhaps a higher incidence in experiment 1. Late emerging weeds would have had

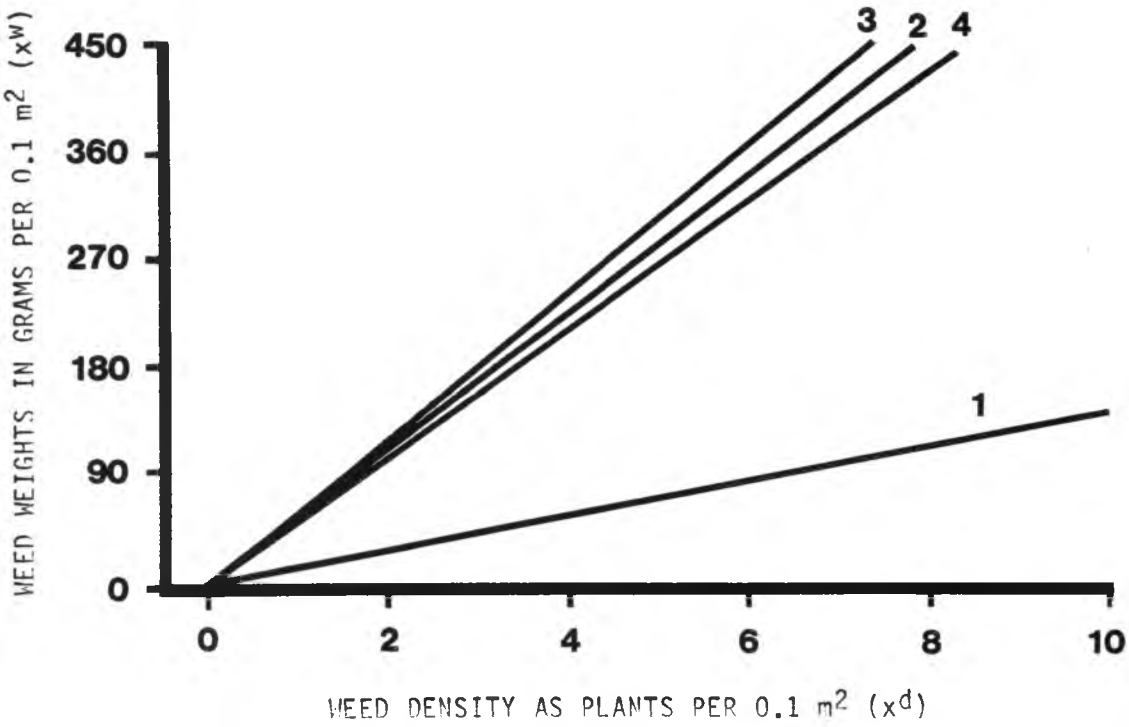

Figure 10. Linear regression lines expressing the relationship between weed weights per unit area and weed density for the 4 experiments.

experiment number	regression equation	r^2
1	$x^w = 24 + 11.5\ x^d$	0.78
2	$x^w = 7 + 52.1\ x^d$	0.60
3	$x^w = 22 + 54.6\ x^d$	0.89
4	$x^w = 6 + 50.6\ x^d$	0.88

to compete in an established weed stand already 25 to 30 cm high and shading the greater portion of the subplot area. It was observed at harvest that some of the weeds were slender, single stemmed and had few leaves, whereas most were 4 to 5 branched at the base, robust and with many leaves. The less robust weeds may have been late emerging plants. Their contribution to x^w would be disproportionately small compared to their contribution to x^d. The make-up of the weed population in experiment 1 would have been a number of large early emerging weeds comparable to those in the other experiments but with many small late emerging weeds in addition.

Regarding the differences between design density and havest density (Table 9), the harvest density seldom exceeded the design density and was more often close to, or less than, the design density. At the higher densities, experiments 2, 3, and 4 fell short of the design by a wider margin than that in experiment 1. Generally, the number of weeds in the subplots at thinning was quite close to the desired density in all experiments. There may have been a certain amount of weed mortality in all experiments but a high degree of replacement in experiment 1, drawing on the high seed reservoir.

Another interpretation of Figure 10 would be that weeds in experiment 1 were not as large as those in the other experiments. Natural infestations of cheeseweed vary widely in their growth habit, presumably due to environmental factors and nutrition. There may have been undetected cultural or environmental differences in the way the first experiment was conducted relative to the others. Fertilizer application, while less than in experiments 3 and 4, were no less in the first experiment than in the second (Table 8). Cabbage head weights were lowest in the first experiment, summer 1982, substantially higher in the second experiment and highest in the fourth experiment, summer 1983. Factors that limited cabbage growth in first trial weed-free subplots may have had an effect on the weed growth as well.

However, there were no apparent differences in the height or growth habit of cheeseweed between the first trial and the others. If nutrients had been limiting and weeds were less robust, then the lower degree of competitiveness, as seen in Figures 1 and 2, would be expected. Decreased competition at lower levels of soil fertility was found by Kleinig and Noble (32) with barnyardgrass in rice and by Buchanan and Burns (9,10) with annual broadleaves in cotton. But this reasoning does not explain why the degree of competitiveness in experiment 1 is similar to the other experiments in regressions with weed weight (Figures 3,4).

While contribution of the late emerging weeds to x^w may not have been large, their contribution to the leaf area of weeds in the canopy may have been appreciable. If there were a relatively large number of late emerging weeds in experiment 1, then, at any x^w, cabbage yield reductions may have been similar for all experiments because the total leaf surface area of the numerous "spindly" weeds may have been equivalent to the leaf surface area of the fewer, but more robust, weeds found in experiments 2, 3, and 4. Hence, the actual degree of shading of the crop may have been very similar for all 4 experiments, in spite of the differences in the relationship between x^w and x^d. Considering yield reductions at equal x^d , first trial yield losses would have been less because the weed count would have included weeds with fewer leaves compared to those in the other 3 experiments.

The make-up of the weed population should be known to predict the effects of competition. In this study it is most likely that the differences in regression lines between experiment 1, compared with experiments 2, 3, and 4, was related to the number of late emerging weeds. The time of weed emergence has been cited as contributing to lack of consistency in yield reductions in experiments by Roberts et al. (44). Drilled summer cabbage yields in 2 years were reduced 95 and 50 percent by weed populations of equivalent fresh weight but differing in their species composition and date of emergence. In the first instance, weeds that competed for more than 3 weeks before removeal caused significant yield loss, whereas yield loss was not incurred until after 7 weeks of competition in the later case. Nelson and Nylund (39) found that a few days difference in the date of weed emergence had a substantial effect on the outcome of competition in peas.

The linear and exponential regression equations with x^d for experiments 2, 3, and 4 indicate a 40 to 56 percent reduction in cabbage yields at 3.2 weeds per 0.1 m^2 (Figures 5 and 6). This compares with 46 percent reduction at 86 weeds per m^2 in a study by Roberts and Bond (43) with drilled cabbage. In the Maui experiment, a 100 percent reduction would be expected at this density. The difference may be that the species complex in Roberts and Bond's experiment was primarily composed of small leaved, prostrate broadleaves, knotweed and chickweed, and annual bluegrass. Tall, large leaved weeds usually are more competitive as was demonstrated in their same study. In another season lambsquarter and stinging nettle were the predominant species in the weed complex, and yields were only 9 percent of that in weeded controls at a density of 300 weeds per m^2. Roberts et al. (44) found a 95 percent reduction in drilled cabbage yields in a complex dominated by lambsquarter at 90 weeds per m^2. Although cheeseweed seems to have caused greater yield reductions (Figures 5, 6), direct comparison is frustrated because weed densities, species complex, and weed emergence were not controlled in these experiments. Hewson's calculated regression line for lambsquarter competition in drilled summer cabbage has a slope somewhat greater than that calculated for cheeseweed (Figures 1, 2, 3, 4) competition in transplanted cabbage (28). At 2 weeds per m^2 lambsquarter would reduce yields by 41 percent, where cheeseweed would reduce yields by 29 to 36 percent (Figures 5, 6). Hewson's study was more like the present one in that a controlled series of weed densities were established and maintained and only lambsquarter was competing. One would expect a greater yield reduction in a drilled crop which would have approximately 3 to 4 additional weeks of competition, in the early part of the season when weed competition can be most critical (9, 13, 17).

The number of maturing seed capsules at harvest, those turning reddish-tan, was recorded as a mean value for 10 weeds in each subplot. These observations were grouped into weed weight (x^w) classes to facilitate comparison across the range of x^w values. These 13 classes each spanned 30 g with class marks at multiples of 20 (Table 10).

There were no differences in the mean number of seed capsules produced per plant across weight classes for experiments 2 and 4 (Duncan's Multiple Range Test, $P=0.05$). The experiment-wise mean number of seed capsules per plant was 28 for experiment 2 and 55 for experiment 4. Seasonal differences in seed production are indicated in that experiment 2 had 78 growing days in January to March, whereas experiment 4 ran 63 days in August and September.

This data indicates the consequences of foregoing weed control measures. If cabbage yield losses at low weed densities were acceptable on a cost-benefit basis, weed control may still be prudent over the long-term. Cheeseweed is capable of producing abundant seed at any density in the course of the crop cycle. With an average of 11 seeds per capsule and 28 capsules per plant, seed production at a density of $x^d = 0.5$ could approach 15.4 million seeds per ha, if the weeds were cut at harvest. The number of flowers and immature seed capsules on a sample of 20 plants at harvest was 4 times the number of seed capsules already mature. Cheeseweed seed is capable of remaining viable in the soil over long periods of time (51).

Weed heights in plot P1, experiment 4, increased with increasing weed density over time (Figure 11). There was little difference in weed heights in the first 3 weeks, but from the fourth week on differences became more pronounced. At harvest the high density subplots had a taller, lusher weed cover.

Average cheeseweed height was greater than average cabbage height after the sixth week in all trials except for plot P1, experiment 3 where shading began after the fifth week from transplanting.

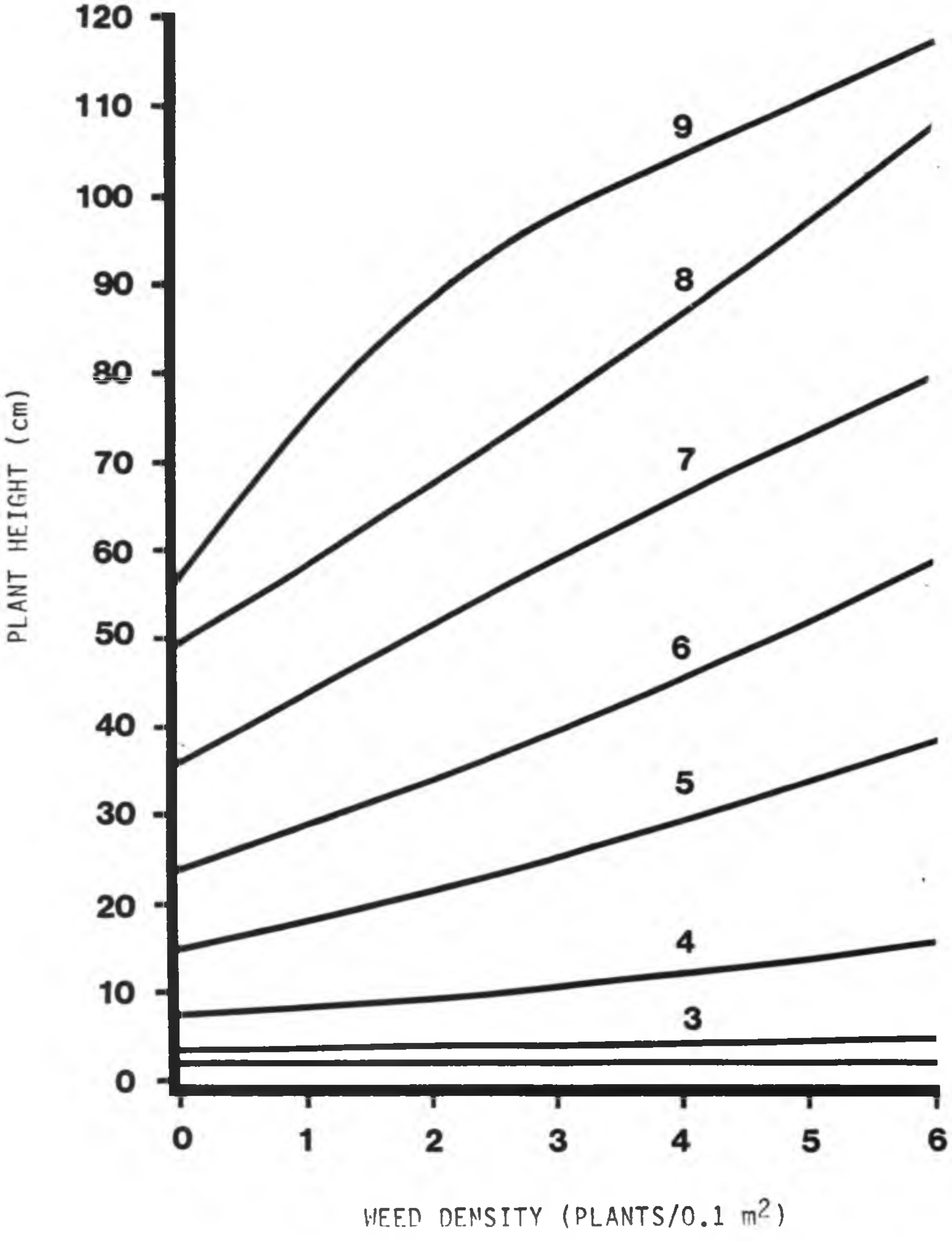

Figure 11. Cheeseweed height at various densities measured 8 consecutive weeks in plot P6, experiment 4. Numbers above the lines represent the week after sowing in which data were recorded.

In the growth analysis experiments, weed densities in plot P6 were to have been uniform throughout. This was not accomplished in experiment 3, as weed densitites in cabbage ranged from 0.8 to 11.7 (Table 11). Weed densities after 6 weeks, when weeds began to shade the cabbage, were somewhat less variable, ranging from 0.8 to 5.4, with 14 subplots between 1.5 and 3.0, 4 above 3, and only 1 below 1.5. Analysis of variance detected treatment differences in cabbage plant weights in weeks 5, 7, 8, and 9, with heavier plants in weed-free subplots. These are the results one would expect if interspecific competition did not begin until cabbage was shaded (Figure 12). No treatment differences in cabbage weight were detected while weeds were small. Mean plant weights in weeks 8 and 9 generally segregated by weed density, with the lowest cabbage weights at the highest x^d.

P6 subplots were a small 1.7 by 1.8 m, consisting of 2 rows of 3 plants each, with a border row of cabbage on all sides. Cheeseweed plants ranged from 0.5 to nearly 1 m in height with average heights of 60, 62, and 86 cm in cabbage and 54, 70, and 80 cm in pure stands in weeks 7, 8, and 9, respectively. Weeds of this height were able to shade adjacent subplots during a few hours of the morning and evening, and it may be that subplots were not sufficiently spaced to eliminate treatment effects from neighboring subplots. Referring to week 9 cabbage weight values (Figure 12), the highest figures were obtained in weed-free subplots with no weedy neighbors. The weed-free subplot with the lowest yield was one which was bordered on opposite sides by weedy subplots. Conversely, the weedy cabbage subplot with the highest yield was bordered on only 1 side by a weedy subplot while the others had

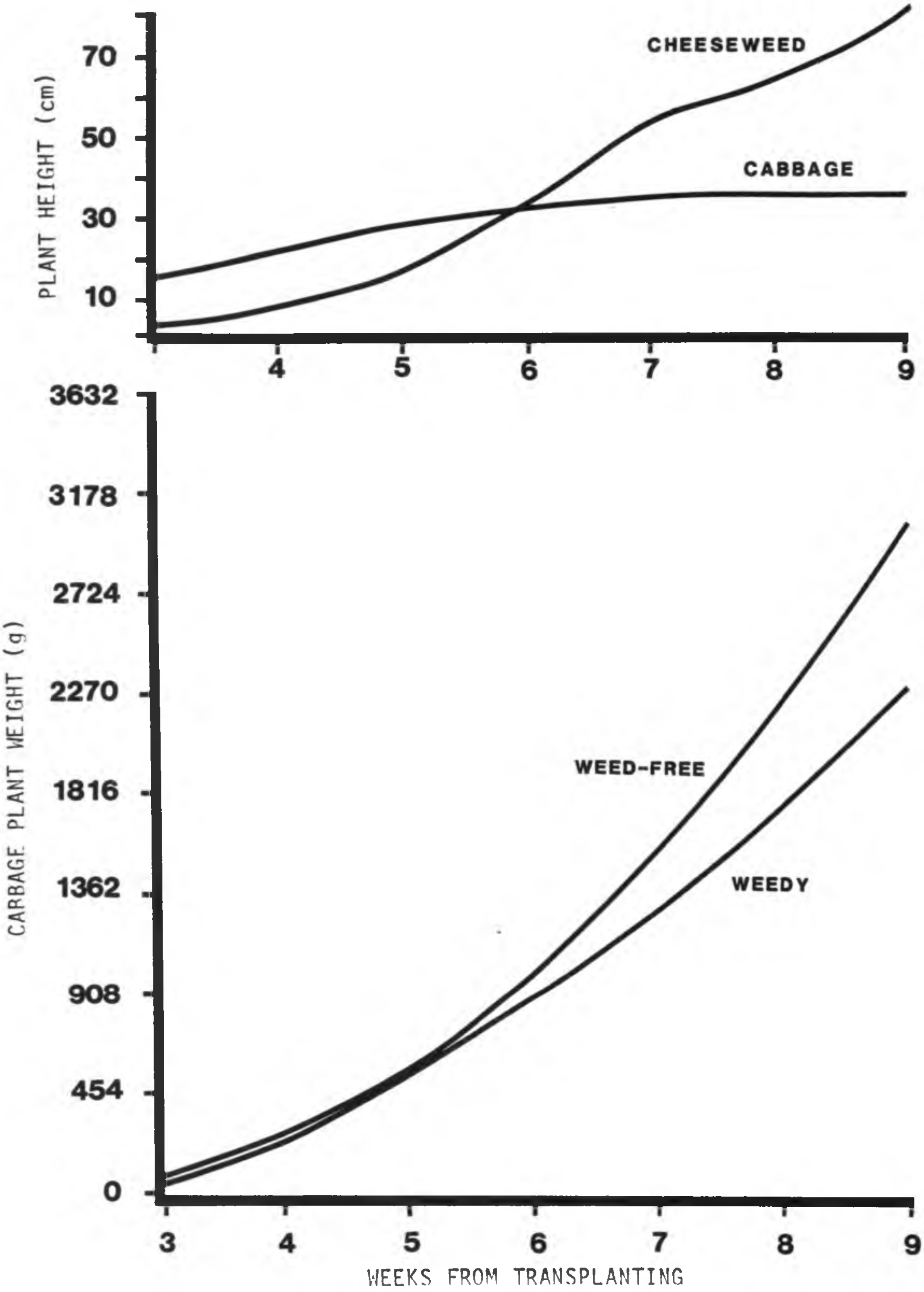

Figure 12. Cabbage growth with and without competition in experiment 3, plot P6.

weedy neighbors on 2 sides. This same pattern was seen in the eighth week.

There were no consistently demonstrated treatment effects on the height of cabbage plants. As cabbage has a spreading growth habit, its response to weed pressure is limited in regards to increasing height. Cabbage height was well near the maximum in the sixth week, when cheeseweed was just beginning to overtake the crop.

Cabbage head diameter was adversely affected by weed competition in a manner consistent with the effects on cabbage plant weight (Table 11).

Weed heights were not shown to be influenced by interspecific competition. Differences were found in treatment means, but treatment means were alternately high or low from 1 week to the next. The coefficients of variation for values in the first 7 weeks were in excess of 33 percent, indicating that differences in treatments were likely due to the wide variation in plant heights. Weed height was demonstrated to be a function of weed density in plot P1 (Figure 11).

Weed emergence in plot P6 for experiment 4 was erratic. Weeds did not emerge until the third week after sowing and stands were spotty. The experiment was designed to have a uniform density of 2 weeds per 0.1 m^2 but, after the fifth week, it was decided to establish a density of 0.4, which was the highest common density among all remaining subplots. At this time weeds varied widely in their height and size within and among subplots. This variation appeared to be more related to weed ages than to treatment effects. Weed weight (x^w) among the subplots of uniform density ranged widely (Table 12).

Differences in cabbage plant weight due to treatment effects were detected by analysis of variance in weeks 2, 3, 4, 5, 7, and 9, with weed-free cabbage consistently larger (Table 12). While these results are in agreement with expectations, the strength of this evidence is questionable. Differences were detected before weeds had even emerged in week 2 and when weeds were less than 3 cm high in weeks 3 and 4. On the basis of results from P1 studies, a density of 0.4 would not be expected to cause detectable differences in cabbage weights. Differences during the early weeks may well have been due to the high degree of variation among cabbage plants. However, mean plant weights in the final weeks, after weeds had overgrown the cabbage, segregated in a manner consistent with P1 results; subplots with high x^w values had the lowest mean cabbage weights (Figure 13).

Lettuce

Lettuce head weights were substantially reduced by cheeseweed competition. A highly significant negative regression was found when lettuce head weights were regressed on x^d and x^w. In each case, a linear equation had the highest coefficient of determination (Figure 14, 15). Hewson (28) found that a curvilinear relationship was evident when drilled lettuce yields were regressed on weed density, but a linear relationship existed in regressions on weed fresh weight. He found that 2.3 and 37 lambsquarters per m^2 reduced yields by 55 and 100 percent, respectively. Comparable densities of cheeseweed reduced head weights by 2 and 22 percent (Figure 14). In comparing yield losses from regressions with weed fresh weight there is fairly close

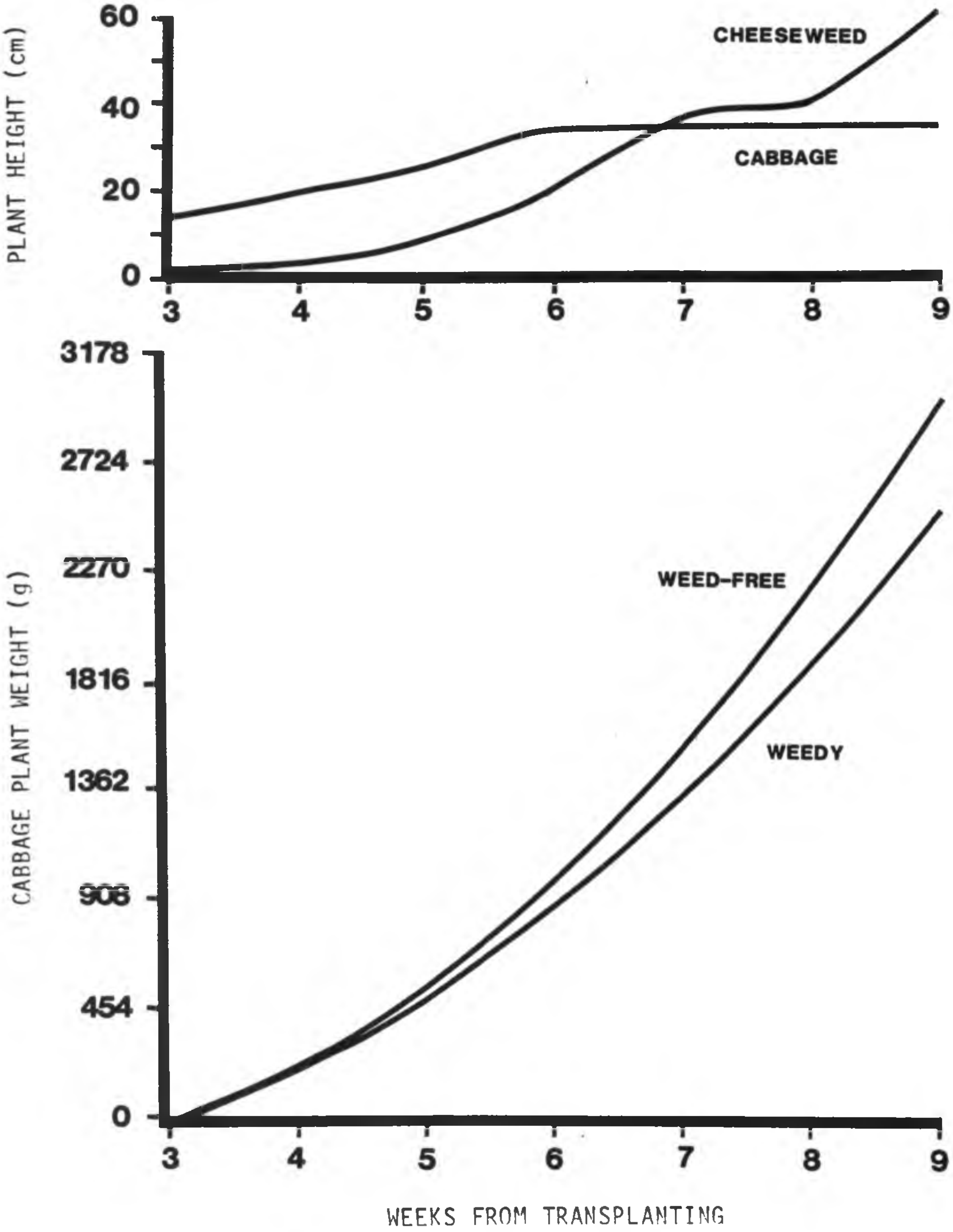

Figure 13. Cabbage growth with and without competition in experiment 4, plot P6.

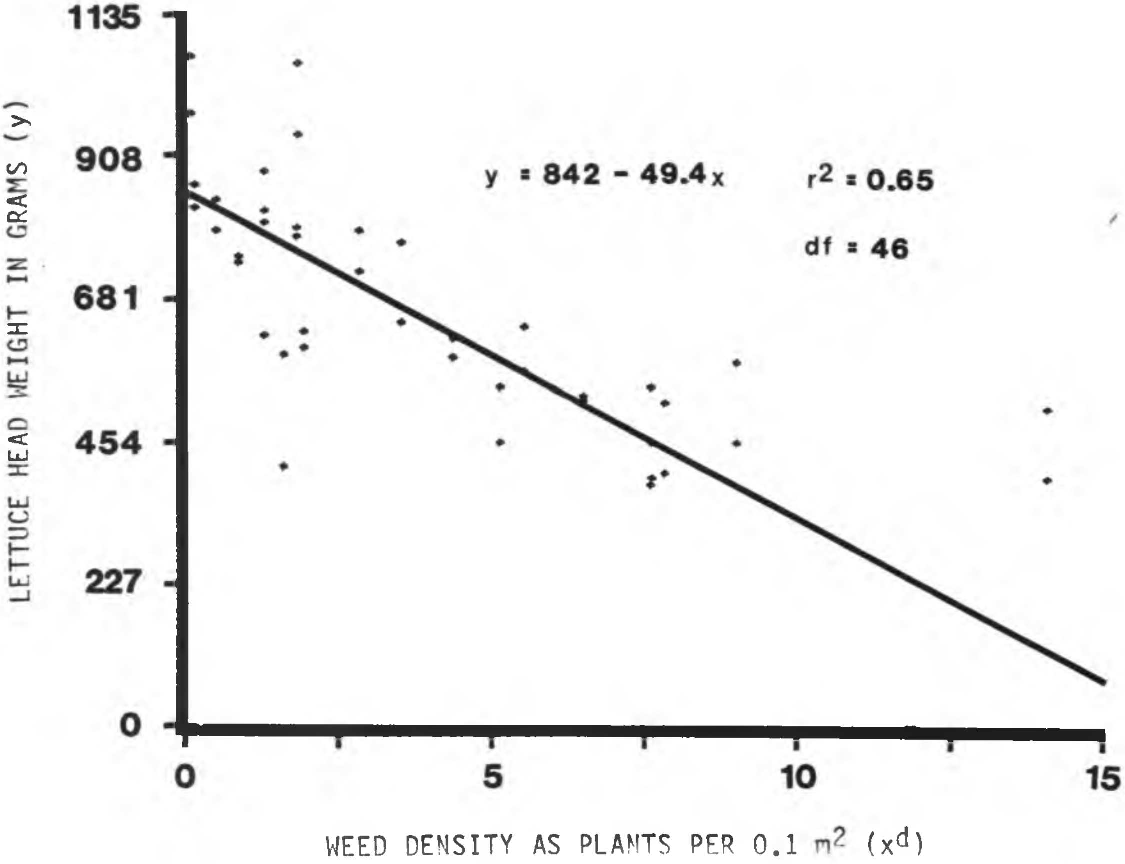

Figure 14. Lettuce head weights under competition with cheeseweed at various densities.

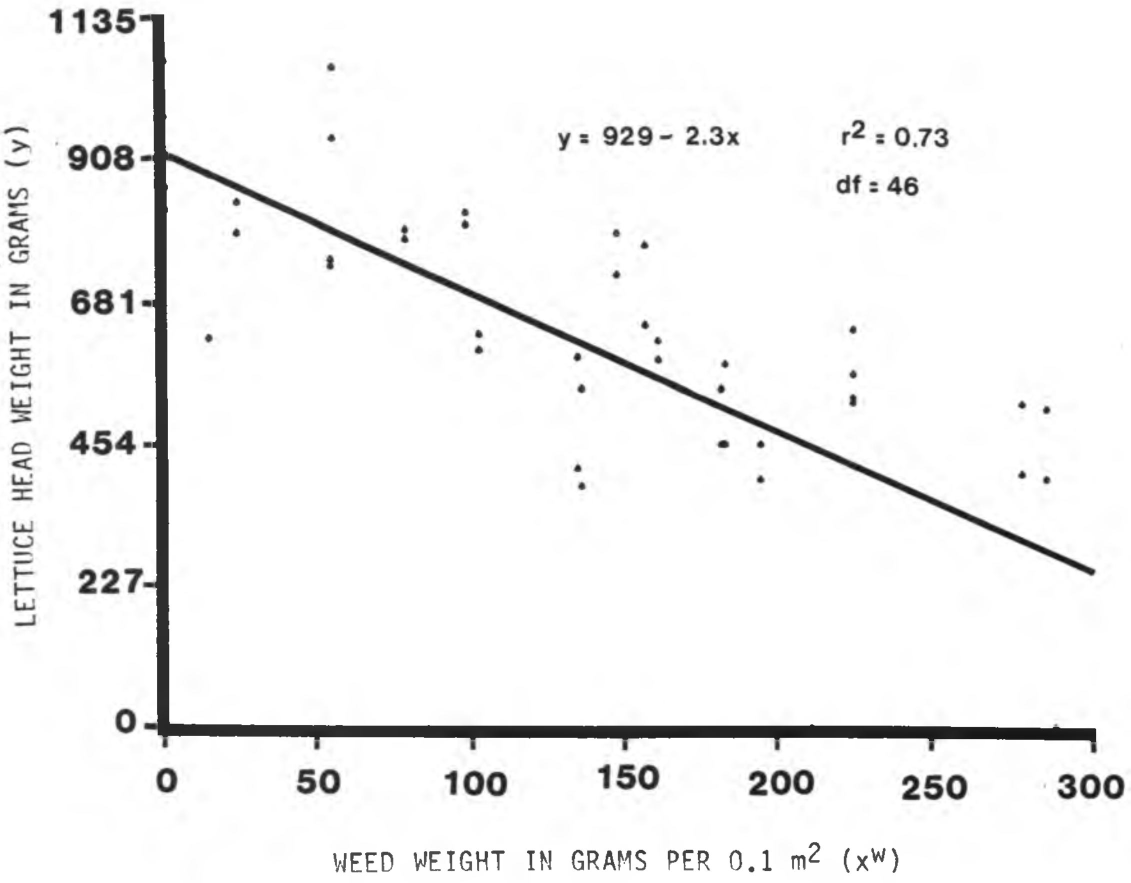

Figure 15. Lettuce head weights under competition with cheeseweed at various weights of weeds per unit area.

agreement with a 59 percent reduction with the equivalent of 227 g/0.1 m^2 of lambsquarters and a 56 percent reduction with the same weight of cheeseweed (Figure 15). Floresca and Nishimoto (24) found a 31 percent reduction in drilled lettuce yield at 4 Emilia per 0.09 m^2 compared to a 34 percent reduction at 4 cheeseweed per 0.1 m^2 in transplanted lettuce (Figure 14). These results are comparable in spite of culture differences, probably because Emilia is not as robust and large leaved as cheeseweed.

In addition to head weight reduction, there was substantial reduction in the crop stand due to rot at high x^d (Figure 15). Few plants survived at x^d greater than 12, and an 80 percent reduction was experienced at an x^d as low as 5.

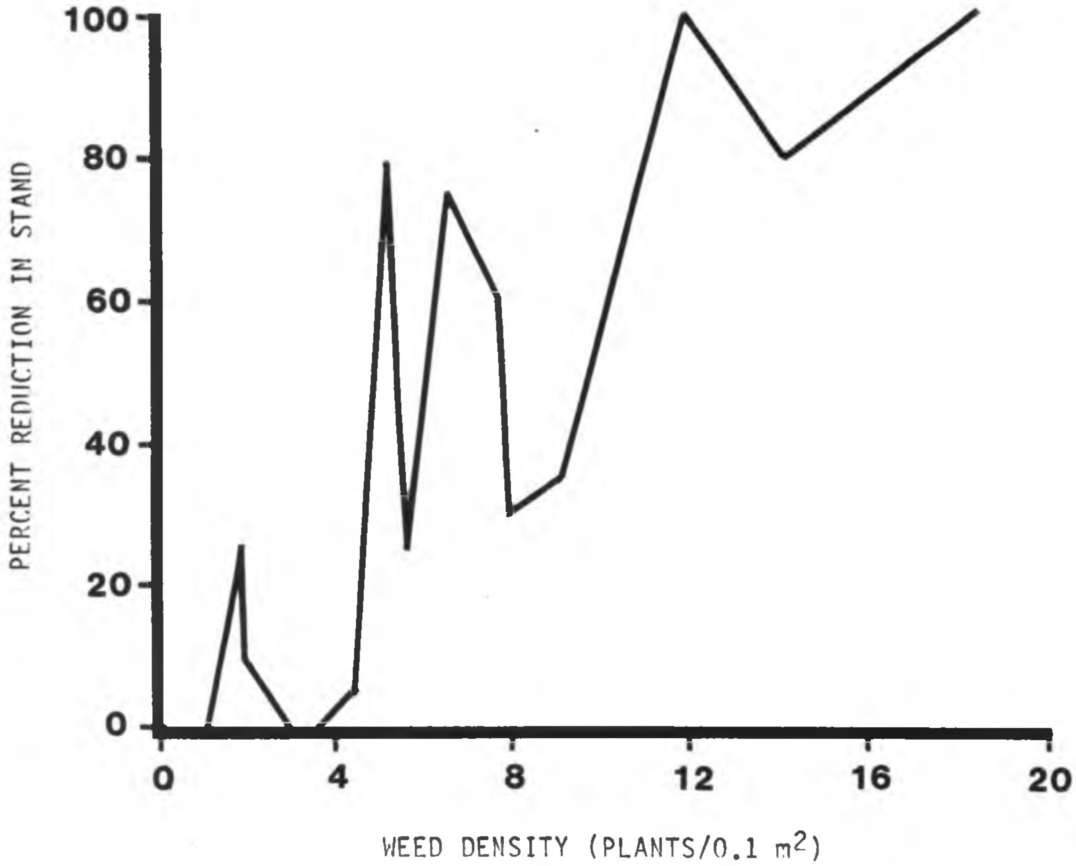

Figure 16. Lettuce stand reduction due to rot in subplots infested with cheeseweed at various densities.

SUMMARY AND CONCLUSIONS

Yield reduction as described by regression equations for cheeseweed competition in transplanted head cabbage, were not substantially different from results found in other competition studies with this crop. Because cheeseweed is a robust plant growing twice to three times the height of cabbage, it caused yield reductions at the lowest treatment densities in this study. Linear and exponential regressions with weed density and weed fresh weight were all valid in depicting the results of competition. The outcome of competition depended on the nature of the weed population. When weeds had a relatively close average weight regression coefficients of the 3 seasonal plantings were very close. The trial with a widely different average weed weight had a substantially different regression slope.

In the growth analysis experiemtns there was evidence that cabbage plant weights were not different in weedy and weed-free treatments until after weeds had overgrown the cabbage in about the sixth week after transplanting. Cabbage had no adverse effect on the growth of cheeseweed. The average heights of cheeseweed plants increased with increased weed densities. Cabbage plant heights were not related to weed densities and generally were close to their maximum height before cheeseweed overgrew the crop.

Cheeseweed produces abundant seed in the course of a crop cycle and should be controlled for this reason as well as to prevent yield loss.

Cheeseweed competition reduced lettuce head weights, and high weed densities contributed to creating ideal conditions for rot organisms.

Table 3. Pesticide application for experiment 1.

Material	Rate*	Days from transplanting
copper hydroxide	7.36	21
diazinon	2.19	21
dimethethoate	1.71	21
copper hydroxide	8.23	28
methomyl	1.97	28
copper hydroxide	12.94	35
pydrin	0.82	35
copper hydroxide	12.94	42
pydrin	0.82	42
dimethoate	3.42	42
copper hydroxide	7.06	49
pydrin	1.23	49
dimethoate	2.05	49

* kg active ingredient/ha

Table 4. Pesticide application for experiment 2.

Material	Rate*	Days from transplanting
copper hydroxide	9.73	3
maneb	9.05	3
diazinon	2.83	3
carbaryl	5.65	3
copper hydroxide	5.80	10
maneb	5.43	10
diazinon	1.70	10
dimethoate	1.13	10
copper hydroxide	5.80	24
maneb	5.43	24
diazinon	1.70	24
dimethoate	1.13	24
copper hydroxide	5.80	36
maneb	5.43	36
diazinon	1.70	36
dimethoate	1.13	36
copper hydroxide	5.80	45
maneb	5.43	45
pydrin	0.41	45
maneb	9.05	50
dimethoate	2.26	50
pydrin	0.62	50

* kg active ingredient/ha

Table 5. Pesticide application for experiment 3.

Material	Rate*	Days from transplanting
copper hydroxide	5.29	7
maneb	4.92	7
methamidophos	3.08	7
copper hydroxide	6.51	14
maneb	6.06	14
pydrin	0.82	14
copper hydroxide	7.73	21
maneb	7.19	21
methamidophos	4.50	21
copper hydroxide	7.73	28
maneb	7.19	28
pydrin	0.82	28
copper hydroxide	8.95	42
maneb	8.33	42
pydrin	1.23	42
copper hydroxide	8.95	49
maneb	8.33	49
methomyl	2.50	49

* kg active ingredient/ha

Table 6. Pesticide application for experiment 4.

Material	Rate*	Days from transplanting
copper hydroxide	6.51	7
maneb	6.06	7
methamidophos	1.89	7
copper hydroxide	6.51	14
maneb	6.06	14
dimethoate	1.89	14
copper hydroxide	7.73	21
maneb	7.19	21
pydrin	0.82	21
copper hydroxide	7.73	28
maneb	7.19	28
methamidophos	4.50	28
copper hydroxide	7.73	35
maneb	7.19	35
pydrin	1.23	35
copper hydroxide	9.36	49
maneb	8.70	49
pydrin	1.23	49

* kg active ingredient/ha

Table 7. Fertilizer and fumigations schedule.

Exp.	Method	Analysis	Rate*	Days from Transplanting
Plot P1				
(1)	broadcast	10-30-10	942	-7
	side-dress	16-16-16	459	15
	fumigation	methyl bromide	707	-7
(2)	broadcast	10-30-10	925	-14
	broadcast	borax	11	-14
	side-dress	21-0-0	362	28
(3)	broadcast	10-30-10	1178	-8
	fumigation	methyl bromide	555	-16
	side-dress	21-0-0	573	27
(4)	broadcast	10-30-10	1178	0
	side-dress	16-16-16	546	22
Plot P6				
(3)	broadcast	10-30-10	1267	-8
	fumigate	methyl bromide	574	-8
	side-dress	21-0-0	602	27
(4)	broadcast	10-30-10	1267	0
	side-dress	16-16-16	583	22

* kg/ha

Table 8. Fertilizer application rates.

Experiment	N	P_2O_5	K_2O	B
Recommended**	168-224*	336-672	168-448	1.19
Plot P1				
1	168	356	168	
2	168	278	92	1.18
3	238	353	178	
4	205	441	205	
Plot P6				
3	253	380	127	
4	220	474	220	

* kg/ha ** UH Extension Service

Table 9. Plant design and harvest weed densities (x^d).

Rep	Designed x^d	x^d for experiment			
		1	2	3	4
1	0.25	-	0.49	0.44	0.33
2	0.25	-	0.66	0.93	0.34
3	0.25	-	0.34	0.72	0.42
4	0.25	-	0.60	0.95	0.72
1	0.50	-	0.96	0.95	-
2	0.50	-	0.86	1.00	0.64
3	0.50	-	1.43	1.14	0.63
4	0.50	-	0.65	1.30	0.55
1	1.00	2.07	1.35	1.62	0.67
2	1.00	1.19	1.17	1.00	0.69
3	1.00	0.36	0.72	1.34	0.56
4	1.00	1.10	0.97	3.26	1.02
1	2.00	1.90	1.76	1.96	0.74
2	2.00	2.63	0.93	-	1.51
3	2.00	2.15	1.20	1.84	1.63
4	2.00	2.73	0.97	2.40	2.81
1	4.00	2.36	3.43	4.70	3.71
2	4.00	5.95	1.51	3.12	2.54
3	4.00	4.59	1.90	4.38	3.05
4	4.00	3.52	2.05	4.57	4.12
1	8.00	9.32	3.00	5.77	3.27
2	8.00	5.95	1.74	3.78	-
3	8.00	5.09	1.02	3.97	5.43
4	8.00	8.46	2.09	7.12	5.19
1	16.00	12.47	-	-	-
2	16.00	9.87	-	-	-
3	16.00	13.41	-	-	-
4	16.00	12.12	-	-	-

x^d = number of plants per 0.1 m^2

Table 10. Mean number of seed capsules per plant at harvest for experiments 2 and 4. Data grouped into classes by x^w.

Weight class	Capsules		Observations per class (n)	
	Experiment			
	2	4	2	4
20	15	23	50	100
40	36	68	70	60
60	34	76	60	40
80	28	89	30	80
100	43	--	10	--
120	--	30	--	20
140	13	33	10	20
160	21	50	10	40
180	--	40	--	20
200	22	--	10	--
220	29	38	10	20
280	--	98	--	10
320	--	58	--	20

x^w = weed weight (g/0.1 m^2)

Table 11. Data from plot P6, experiment 3. Values were recorded from 4 weedy and 4 weed-free subplots each week.

Week	CV		Subplot values							
3	32	wt	93	67	61	60	58	53	48	41
		ht	18	17	17	16	17	16	16	16
		x^w	1	0	0	0	1	1	0	0.2
		x^d	8	0	0	0	11	3	0	1
4	37	wt	263	260	252	219	166	156	154	-
		ht	24	23	23	24	21	22	21	-
		x^w	1	1	0	0	0	1	1	-
		x^d	3	1	0	0	0	3	3	-
5*	41	wt	812	631	615	546	463	429	404	400
		ht	30	29	28	28	27	27	26	26
	23	dm	6	5	5	5	4	4	4	4
		x^w	0	0	3	0	2	0	8	2
		x^d	0	0	3	0	2	0	3	2
6	40	wt	1019	996	917	598	594	587	445	-
		ht	32	35	33	30	27	27	26	-
	29	dm	10	9	8	6	6	6	5	-
		x^w	0	9	0	0	8	10	0	-
		x^d	0	5	0	0	2	2	0	-
7*	28	wt	1886	1593	1534	1447	1337	1327	1222	1148
		ht	36	35	43	36	38	34	32	32
	19	dm	14	12	10	12	12	11	12	10
		x^w	0	0	185	42	109	0	0	10
		x^d	0	0	5	2	5	0	0	1
8*	29	wt	3054	3043	2616	2505	2388	2198	2033	1897
		ht	38	36	38	40	36	35	34	34
	16	dm	17	18	16	17	15	15	14	13
		x^w	0	0	52	0	0	73	34	34
		x^d	0	0	2	0	0	2	3	2
9*	39	wt	3721	3505	2852	2743	2398	1963	1734	1728
		ht	37	37	38	39	30	39	36	29
	18	dm	18	17	17	16	16	13	13	12
		x^w	0	0	116	0	0	178	193	0
		x^d	0	0	2	0	0	2	2	0

x^w = weed weight per 0.1 m^2 x^d = weed density per 0.1 m^2
wt = cabbage plant weight (g) dm = cabbage head diameter (cm)
ht = cabbage plant height (cm) CV = coefficient of variation
* treatment differences at $P = 0.05$

Table 12. Data from plot P6, experiment 4. Values were recorded from 4 weedy and 4 weed-free subplots each week.

Week	CV		Subplot values							
2*	46	wt	11	10	9	9	8	7	6	6
		x^w	0	0	0	0	0	0	0	0
3*	29	wt	47	44	40	36	35	29	26	-
		x^w	0	0	0	0	0	0	0	-
4*	38	wt	175	150	146	128	114	109	103	77
		x^w	0	0	0	0.2	0	0	0	0.1
5*	30	wt	618	529	516	484	472	443	323	318
		x^w	0	0	0.3	0.4	0	0.5	1.4	0
6	20	wt	1145	1136	1108	1014	929	919	844	807
	15	dm	10	10	10	9	8	8	7	8
		x^w	4	0	0	3	0	0	2	1
7*	33	wt	2092	1809	1750	1652	1371	1332	891	-
	22	dm	16	15	14	13	13	13	9	-
		x^w	0	0	12	0	5	0	16	-
8	37	wt	2316	2263	2142	2097	1784	1528	1219	-
	24	dm	15	15	14	13	13	12	10	-
		x^w	0	17	0	0	10	10	0	-
9*	32	wt	3189	3156	3066	2993	2962	2813	2055	1726
	16	dm	17	17	17	17	17	17	15	14
		x^w	0	17	0	0	118	0	28	89

x^w = weed weight per 0.1 m^2 x^d = weed density per 0.1 m^2
wt = cabbage plant weight (g)   dm = cabbage head diameter (cm)
CV = coefficient of variation
* treatment differences at P = 0.05

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